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All-optical interconnection and routing memory by photorefractive full liner resonator

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1. Introduction

Recently, all-optical interconnection devices with photorefractive crystal has been focused on for pure optical control, low thermal generation and high integration[1–2]. In this report, we propose an all-optical interconnection device by photorefractive (PR) full liner resonator with a beam splitter and a cat self-pumped phase conjugate mirror. In this device, the connection pattern is maintained by optical feedback of the input signal without continuous illumination of the control beam or any fixing techniques such as electrical fixing, thermal fixing, two step process, and so on[3–5]. Therefore we can also use this device as the optical memory that keeps the routing pass of the signals.

The input signals are wired to desired output channels in free space via the index grating induced by the control beam in the crystal. This connection pattern is reconfigurable by the illumination of the control beam. The index grating in the photorefractive crystal, in general, is volatile, and it is erased by the exposure of the input signal. In our interconnection device, the part of the output signal oscillates between the beam splitter and the cat mirror, and the rewriting effect by this resonance sustains the index grating against the erasure effect of the input signal. As a result, the connection, which pattern is once formed or configured by the control beam, can be held by only the input signal.

We explain the concept of the all-optical interconnection device. We analyze the output conversion efficiency for the reflectivity of the beam splitter and the cat mirror, which determines the feedback rate of the output signal, and the coupling strength threshold for maintaining the index grating.

2. All-optical interconnection and routing memory

Figure.1 shows the conceptual diagram of the all-optical interconnection. PRC is a photorefractive crystal. BS and CAT are respectively a beam splitter and a cat self-pumped phase conjugate mirror. The input signal beam and the control beam illuminates the PRC, then the double phase conjugation by these beams occurs. The signal beam is diffracted to the output port as the phase conjugate beam of the control beam. A part of this diffracted beam is transmitted through the BS1 and the BS2. Then this beam is focused perpendicularly by a cylindrical lens and wired to desired output channel. In figure.1, the input channel 1, 2, 3 and 4 is connected to the output channel 1, 4, 3 and 2 respectively. On the other hand, the beam reflected by the BS1 is incident to the PRC again and it is used to maintain the index grating in the PRC as the following process. When the beam is transmitted through the PRC, the interference between the original beam and the beam diffracted by the index grating in the PRC rewrites the index grating. Further, the beam, which is transmitted through the PRC and is reflected by the CAT, and the input signal beam interferes, so this interference rewrites the index grating in the crystal. If the two rewriting effect of the index grating by these interference is sufficiently larger than the erasure effect of the input signal beam, the index grating is maintained even if the control beam is turned off. As a result, the connection, which pattern is once memorized or configured by the illumination of the control beam, can be held by using a part of the power of the input signal beam.

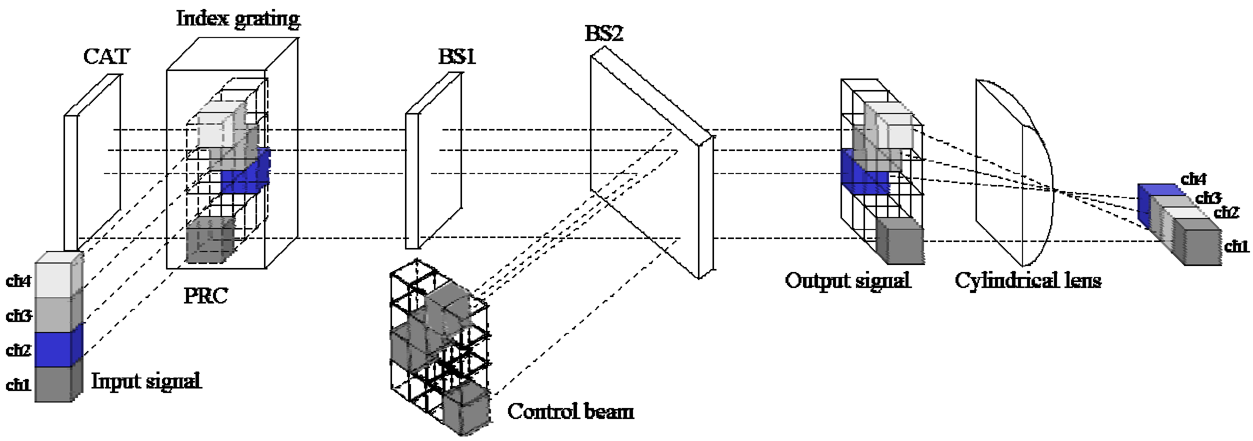

Figure.1 Photorefractive full linear resonator

3. Analysis

The interaction of the beams in the crystal is represented by following coupling wave equations

$$\frac{dA_1}{dz} = -\frac{\gamma}{I_0}\left(A_1 A_4^* + A_2^* A_3\right)A_4 \tag{1a}$$

$$\frac{dA_2^*}{dz} = -\frac{\gamma}{I_0}\left(A_1 A_4^* + A_2^* A_3\right)A_3^* \tag{1b}$$

$$\frac{dA_3}{dz} = \frac{\gamma}{I_0}\left(A_1 A_4^* + A_2^* A_3\right)A_2 \tag{1c}$$

$$\frac{dA_4^*}{dz} = \frac{\gamma}{I_0}\left(A_1 A_4^* + A_2^* A_3\right)A_1^* \tag{1d}$$

where γ is coupling coefficient, A_1, A_2, A_3, A_4 are electric amplitudes of the forward pump beam, backward pump beam, phase conjugate beam and probe beam, respectively. I_0 is the total intensity of these beams, which is calculated as $I_0 = I_1 + I_2 + I_3 + I_4$, where $I_j = |A_j|^2$ $(j = 1-4)$. The boundary conditions of beams on the crystal is given as

$$A_1(0) = A_2(0)e^{i(2kL_1+\pi/2)}\sqrt{M_1} \tag{2a}$$

$$A_2(L) = A_1(L)e^{i\{2(kL_2+\theta_c)+\pi/2\}}\sqrt{M_2} \tag{2b}$$

where M_1 and M_2 are the reflectivity of the CAT and the BS1 respectively. L_1 is the distance between $z = 0$ and the CAT. L_2 is the distance between $z = L$ and the BS1. k is wave number of the beam and θ_c is the change phase quantity of the beam propagation through the crystal.

From these equations, the output conversion efficiency *V*, which is the ratio of the intensity of the output signal beam to the one of the input signal beam, is derived as

$$V = \frac{(1-M_2)I_1(L)}{I_4(0)} = (1-M_2)\frac{(1+\Delta)(1-M_1R)}{M_2\{1-\Delta-(1+\Delta)M_1\}} \tag{3}$$

where R is

$$R = \frac{(\Delta+1)^2|T|^2}{M_2\left|\Delta T + \sqrt{\Delta^2 + (\Delta+1)^2/M_2}\right|^2} \tag{4}$$

and the variable Δ satisfies the following equation

$$\sqrt{M_1M_2} = \left|\frac{T + \sqrt{\Delta^2 + (\Delta+1)^2/M_2}}{\Delta T + \sqrt{\Delta^2 + (\Delta+1)^2/M_2} + (\Delta+1)T/M_2}\right| \tag{5a}$$

$$T = \tanh\left(\frac{\gamma L}{2}\sqrt{\Delta^2 + \frac{(\Delta+1)^2}{M_2}}\right) \tag{5b}$$

We show the output conversion efficiency *V* in figure.2 under assumption of $\gamma L = 1$. In this figure, we find that the output conversion efficiency *V* depends on the reflectivity of the BS and the CAT. The output conversion efficiency *V* becomes larger as the reflectivity of the CAT becomes larger. On the other hand, the reflectivity of the BS has the optimum value for any reflectivity of the CAT. For example, the optimum reflectivity of the BS is $M_2 = 0.7$ under assumption of $M_1 = 0.3$ and $\gamma L = 1$. In this case, the output conversion efficiency is 0.1. We also find that the coupling strength threshold exists in order to generate the output beam. The coupling strength threshold γL for sustention of connection satisfies

$$\sqrt{M_1M_2} - e^{\gamma L} = 0 \tag{6}$$

Figure.3 shows the coupling strength threshold for the reflectivity of the BS and the CAT. In this figure, the coupling strength threshold depends on the reflectivity of the BS and the CAT. The coupling strength threshold approaches to zero as the reflectivity of the BS and the CAT becomes larger. Therefore we can make the coupling strength threshold small by adjusting the reflectivity of the BS and the CAT.

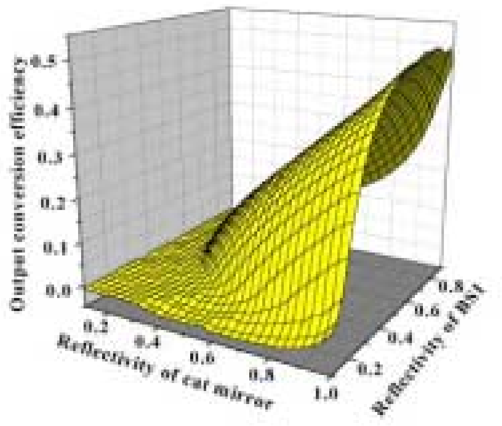

Figure.2 Output conversion efficiency

4. Conclusion

We have proposed an all-optical interconnection by photorefractive full linear resonator in which the connection pattern is maintained by the feedback of the input signal without the continuous illumination of the control beam. We can also use our interconnection device as the optical memory that keeps the routing pass of the signals. We have analyzed the output conversion efficiency and the coupling strength threshold for the reflectivity of a beam splitter and the cat mirror. We have shown that we can make the coupling strength threshold small by adjusting the reflectivity of a beam splitter and the cat mirror.

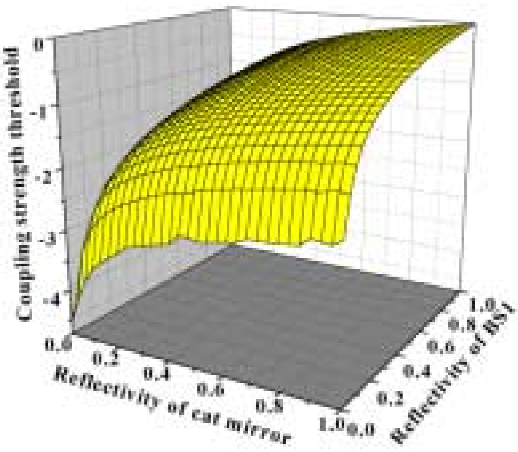

Figure.3 Coupling strength threshold

We plan to the experiment on 3×3 optical interconnection to verify the numerical analysis.

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